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Growth performance, carcass characteristics and meat quality of group-penned surgically castrated, immunocastrated (Improvac®) and entire male pigs and individually penned entire male pigs

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The objective of the study was to compare growth performance, carcass characteristics, meat quality and fatty acid composition of the adipose tissue of group-penned barrows, immunocastrated boars and entire males. Furthermore, the effect of housing of entire males on the aforementioned parameters was evaluated. At 55.2 days of age, 52 Swiss Large White pigs were blocked by litter and assigned by BW to four experimental groups: barrows (C), immunocastrated boars (IC), entire males (EMG) reared in group pens and entire males (EMP) reared in individual pens. In experiment 1, the effects of the method of castration were investigated (experimental groups C, IC and EMG). In experiment 2, the effects of housing on entire male pigs were evaluated (experimental groups EMG and EMP). All pigs had ad libitum *access to standard diets from weaning to 107 kg BW. The two vaccinations (Improvac®) were applied to the IC pigs at an average BW of 22.6 and 73.0 kg. In experiment 1, average daily gain (ADG) did not ($P > 0.05$) differ among the experimental groups. However, EMG consumed less feed and had a better feed-conversion ratio than C ($P < 0.001$ for each). For IC, intermediate values were observed, which differed ($P < 0.001$) from EMG and C. Lean meat percentage decreased ($P < 0.05$) from EMG to IC, and from IC to C. The androstenone and skatole levels were higher ($P < 0.05$) in the adipose tissue of EMG than IC and C. Shear force values were higher ($P < 0.01$) in the longissimus muscle of C and EMG, compared to IC. The concentration of saturated fatty acid in the adipose tissue increased ($P < 0.001$) from EMG to IC, and from IC to C pigs, and that of polyunsaturated fatty acid decreased ($P < 0.001$). In experiment 2, ADG did not ($P > 0.05$) differ between EMP and EMG. However, EMP pigs consumed more feed than EMG pigs and had a poorer feed efficiency ($P < 0.01$ for each). In conclusion, EMG pigs had a better feed efficiency than IC pigs and their carcasses were leaner, but the risk of boar tainted pork was elevated. Group-housing negatively affected average daily feed intake but not ADG of entire males. At the moment, immunocastration offers a good approach to avoid castration and minimize the risk of boar taint.*

Keywords: carcass and pork quality, entire male pigs, housing, immunocastration, performance

Introduction

In most European countries, male piglets are castrated during their first days of life, in order to avoid meat with boar taint. In 2010, castration of young male piglets without pain relief will be prohibited in Switzerland (TSchV, 2008). Fattening entire male pigs and active immunization against gonadotropin-releasing hormone (GnRH) (so called immunocastration) offer possible alternatives to common surgical castration practice.

Due to the anabolic effects of testicular hormones, entire males are more feed efficient and consequently their carcasses are leaner (Xue *et al.*, 1997). However, the presence of boar taint, which depends mainly on the concentration of androstenone, skatole and indole stored in tissue lipids (Claus *et al.*, 1994), can reduce consumer's acceptance of pork. In a recent study comparing the growth performance of group-penned entire males and barrows, we reported

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that, entire males grew slower (774 *v.* 830 g/day), consumed less feed (1.88 *v.* 2.23 kg/day) but were more feed efficient (2.43 *v.* 2.69 kg feed/kg gain) than barrows (Pauly *et al.*, 2008). The lower average daily feed intake (ADFI) and lower average daily gain (ADG) of entire males compared to barrows, is in agreement with Lawlor *et al.* (2003) and Dunshea *et al.* (2001) but in contrast to earlier results reported by Campbell *et al.* (1989) and Dunshea *et al.* (1993). Based on earlier observations (Pauly *et al.*, 2008), it is unclear whether appetite is limiting or feed intake is low because of increased aggressive behaviour of group-penned entire males. We hypothesized that when social interactions and aggressive behaviour are limited by raising the boars in individual pens, their full growth potential could be exploited.

Active immunization against GnRH by using Improvac® (Pfizer Ltd, Zurich, Switzerland) inhibits the sexual development of boars by disrupting the hypothalamic-pituitary-gonadal axis. As a result, the development of testes and hormone synthesis is hindered. From a meat quality point of view, the most important effect of active immunization is that the synthesis of androstenone is suppressed. Furthermore, reduced levels of testicular steroids in immunocastrates accelerate the metabolic clearance of indolic compounds, thus, lowering skatole and even indole concentrations at tissue level (Zamaratskaia *et al.*, 2008). Until the second vaccination, immunocastrates grow at a similar rate as entire male pigs (Dunshea *et al.*, 2001). In several studies comparing barrows, immunocastrates and entire male pigs, it was found that immunocastrates had higher ADG and better feed conversion ratio (FCR) than barrows (Dunshea *et al.*, 2001; Turkstra *et al.*, 2002). When entire males are compared to immunocastrates, results are inconsistent (Dunshea *et al.*, 2001; Turkstra *et al.*, 2002; D'Souza and Mullan, 2003). The available data suggest that the growth performance and carcass characteristics of immunocastrated boars are strongly influenced by two key factors. These are the growth potential of entire males prior to the second vaccination, and the time interval between the second vaccination and slaughter (Dunshea *et al.*, 2001; Metz *et al.*, 2002).

Castration influences carcass leanness. The adipose tissue of entire male pigs has a lower lipid content and the degree of unsaturation is higher than in barrows (EFSA, 2004). Through variation in the backfat thickness, one can hypothesize that fatty acid composition of immunocastrated boars should be intermediate between entire males and barrows.

The primary objective of this study was to compare growth performance, carcass characteristics, meat quality traits and fatty acid composition of the subcutaneous adipose tissue from group-penned barrows, immunocastrates and entire male pigs reared under Swiss husbandry conditions and fed standard growing–finishing diet used in Switzerland (experiment 1). A second objective of this study was to elucidate the reasons for the low ADFI and ADG of entire males by rearing entire male pigs either in a group pen or in individual pens (experiment 2).

Material and methods

The Swiss Federal Committee for Animal Care and Use approved all procedures involving animals.

Experiment 1: animals and treatments

In experiment 1, a total of 39 Swiss Large White male pigs originating from 12 litters (11 litters with three siblings/litter; 1 litter with six siblings/litter) were included. From weaning until the start of the experimental period (BW = 27.6 ± 0.5 kg; age = 74.5 ± 1.3 days (mean ± s.e.)), pigs were group penned (13 pigs/pen) and had *ad libitum* access to a standard starter diet formulated according to Swiss feeding recommendations (ALP, 2005). The pens for the weaned pigs were equipped with single-space computerized feeders (Mastleistungsprüfung MLP-RAP; Schauer Agrotronic AG, Sursee, Switzerland) which allowed for the recording of individual feed intake. At an average BW of 15.3 ± 0.6 kg (age = 55.2 days), the three littermates were allocated to three experimental groups (barrows (C; $n = 13$), immunocastrated male pigs (IC; $n = 13$) and entire male pigs (EMG; $n = 13$)) to assure equal average BW between the experimental groups. After the piglets were allocated, the C pigs were castrated after injecting a local anaesthesia (Lidocain–Epinephrin 2%; Streuli Pharma AG, Switzerland). Under Swiss commercial practice, castration is performed within the first 14 days of age. The reason for the delayed castration in this experiment was to assure group homogeneity with respect to BW at the start of the trial. At an average BW of 27.6 ± 0.5 kg, the C, IC and EMG pigs were moved to the growing–finishing barn.

Vaccination

The IC pigs were vaccinated with Improvac® , which contains a modified form of gonadotropin-releasing factor (200 μg GnRF–protein conjugate/ml) in an aqueous adjuvant system. Each IC pig was vaccinated twice subcutaneously behind and below the base of the ear with 2 ml of Improvac® . Furthermore, as a control, the C and EMG pigs were injected with a saline solution (0.8% (w/v)). All pigs were injected at one time. The first and second injections were carried out when the heaviest IC reached 25 kg of BW (mean ± s.e. of all IC pigs: BW = 22.6 ± 0.8 kg; age = 67 ± 1 days) and 80 kg of BW (mean ± s.e. of all IC pigs: BW = 73.0 ± 1.5 kg; age = 131 ± 1 days), respectively. The rectal body temperature of the C, IC and EMG pigs was assessed 48 h before and at 0, 4, 24 and 48 h after the injection. In addition, at the same time points, based on visual observations and palpation, the injection site was scored on a scale from 1 to 4 (score 1 = normal, not more than a visible injection site with less than 0.5 cm diameter zone of cutaneous erythema surrounding it; score 4 = severe, visible and palpable subcutaneous or intramuscular swelling as well as evidence of irritation at the injection site with >5 cm diameter zone of cutaneous erythema surrounding it).

Experiment 2: animals and treatments

Experiment 2 was conducted in parallel with experiment 1. Thus, in addition to the 39 pigs originating from 12 litters used

in experiment 1, 13 additional male piglets from those litters (two from one litter and one per litter from 11 litters) were selected at 55.2 days of age. Compared to the EMG pigs, these entire male pigs (EMP; $n = 13$) were reared from weaning until slaughter in semi-slatted individual pens (2.6 m^2/pig) with the laying area slightly covered with sawdust and straw, in environmentally controlled buildings (22°C and 60% to 70% relative humidity). They had free access to water. EMP pigs were also injected with a saline solution (0.8% (w/v)).

Growth experiment, slaughter procedure and carcass measurements

The growth trial (experiments 1 and 2) lasted from May to September 2007 and was divided into a growing (27 to 63 kg BW) and a finishing (63 to 107 kg BW) period. In experiment 1, to evaluate the effect of vaccination on growth performance, the finishing period was divided into an early finishing period (63 kg BW to second vaccination) and a late finishing period (second vaccination to slaughter). The C, IC and EMG pigs were reared for the entire experimental period in semi-slatted group-pens (13 animals/pen; 1.5 m^2/animal) with the laying area slightly covered with sawdust and straw, in environmentally controlled buildings (22°C and 60% to 70% relative humidity). Pens were equipped with two drinkers and two single-space computerized feeders (Mastleistungsprüfung MLP-RAP) as described earlier (Bee *et al.*, 2008).

All pigs had *ad libitum* access to the same growing and finishing diets (Table 1). Individual feed intake was recorded weekly for the EMP pigs and at each visit to the feeder for the C, IC and EMG pigs, respectively. The BW of all animals was determined once a week. From 80 kg BW until slaughter, pens were cleaned daily and barn ventilation was set at maximum-power to reduce skatole absorption through the skin and the lungs (Hansen *et al.*, 1994). Two pigs (one C and one EMG) died during the trial. The cause of death was not related to the treatments.

Animals were slaughtered 2 days after reaching 103 kg BW. Feed was withdrawn from the pigs 12 h before transportation to a nearby commercial abattoir (approximate transport time = 15 min). During transport and lairage, slaughter pigs from different pens were separated from each other. At the abattoir, animals were electrically stunned, exsanguinated, scalded, mechanically de-haired and eviscerated. Internal organs were removed and hot carcass weight was obtained. The weight of the testes, bulbourethral and salivary glands as well as the heart, liver and kidneys were assessed. At 30 min after exsanguination, the carcasses entered the air-chilling system (3°C) for 24 h. One day after slaughter, the left side of each carcass was weighed and dissected according to the meat cutting standards applied by the Swiss Performance testing Station (MLP, Sempach, Switzerland), as described earlier (Bee, 2001).

Meat quality measurements

The pH of the longissimus muscle (LM) at 30 min and 24 h *post mortem*, was measured using a pH meter (pH196-S, WTW, Weilheim, Germany) equipped with an electrode (Eb4; WTW) and a temperature probe. Sets of measurements were obtained at the 10th-rib of the right carcass side at 30 min, by insertion of the pH and temperature probe between the ribs from the inside of the carcass. At 24 h *post mortem*, the LM from the 10 to 13th-rib level was excised and pH was determined at the 10th-rib level. Subsequently, four 1.5-cm-thick LM chops were cut and labelled A, B, C and D. From chops A and C, drip loss was determined as the amount of purge formed during storage of chops at 4°C for 48 h (Honikel, 1998). From the chops B and D, light reflectance coordinates (L^*: lightness, a^*: redness and b^*: yellowness) of the muscle surface were determined following a 10-min bloom, using a Chroma Meter CR-300 with a D65 light source (Minolta, Dietikon, Switzerland). Subsequently, these samples were vacuum-packaged and stored at −20°C until thaw and cooking loss, as well as Warner-Bratzler shear force were assessed. The frozen samples were thawed for 24 h at 2°C, subsequently, kept at room temperature for 1 h and the thaw loss was determined. Both samples were then cooked on a grill plate (Beer Grill AG, Zurich, Switzerland) at 190 to 195°C, to an internal temperature of 69°C, and cooking losses were measured. Using a Warner-Bratzler shear device (Model

Table 1 *Composition of the growing and finishing diet, as-fed basis*

Ingredients (%)	Diet	
	Growing	Finishing
Wheat	27.2	62.2
Barley	15.0	3.8
Corn	6.9	3.1
Wheat starch	19.7	2.8
Sugar beet pulp	2.1	10.0
Soybean cake	22.7	12.4
Sugar beet molasse	3.0	3.0
L-lysine-HCl	0.28	0.25
DL-methionine	0.13	0.06
L-threonine	0.13	0.08
L-tryptophane	0.01	
Dicalcium phosphate	1.0	0.71
Sodium chloride	0.36	0.2
Pellan†	0.3	0.3
Calcium carbonate	0.78	0.7
Vitamin–mineral-premix	0.4	0.4
Analysed composition (g/100 g DM)		
Crude protein	18.6	16.6
Lysine	11.4	9.2
Crude lipid	2.6	2.1
Crude fibre	3.4	4.5
Calcium	0.80	0.70
Phosphorus	0.61	0.54
Calculated energy content		
DE‡ (MJ/kg DM)	15.8	15.4

DM = dry matter.
†Pellan = a binder that aids in pellet formation (Mikro-Technik GmbH & Co. KG, Germany).
‡DE = digestible energy content (MJ/kg) calculated from nutrient content (expressed in g/g DM) according to ALP (2005).

3000, G-R Electric Mfg Co., Manhattan, KS, USA), shear force was measured as described earlier (Bee *et al*., 2007). From each carcass, adipose tissue samples (both layers) were collected at the 10 to 14th-rib level, vacuum-packaged and stored at −20°C until further analysis.

Adipose tissue analysis

The androstenone, skatole and indole concentrations in the adipose tissue were measured by HPLC as described earlier (Pauly *et al*., 2008), and the levels were expressed as μg/g tissue. In addition, the fatty acid profile in the adipose tissue was determined as described earlier (Bee *et al*., 2007).

Statistical analysis

The data on growth performance, carcass characteristics and meat quality traits, as well as the fatty acid composition and androstenone, skatole and indole concentrations of the adipose tissue, were separately analysed for each experiment using the MIXED procedure of SAS (version 9.1; SAS Institute, Cary, NC, USA), and the statistical analysis was based on the following model:

$$X_{ijk} = \mu + \alpha_i + \beta_j + \varepsilon_{ijk},$$

where X_{ijk} is the observed parameter, μ is the overall mean, α_i is the experimental treatment (fixed effect), β_j is the litter (random effect) and ε_{ijk} is the error.

The individual pig served as the experimental unit. Least square means were separated using the PDIFF option ($P < 0.05$). Tendencies were established at $P < 0.10$. Due to lack of normality of the residuals, the concentrations of skatole were transformed with $1/\sqrt{x}$. Normality of the residuals of the androstenone and indole levels could not be achieved by data transformation, therefore the data were analysed with the non-parametric Friedman test, with the experimental groups as fixed and litter as random effects. To determine differences between treatments, the Bonferroni procedure was used with the two-tailed Wilcoxon's signed-rank test ($P < 0.05$). Spearman's rank correlations were calculated between androstenone, skatole and indole tissue concentrations, and organ weights and length.

Results

Growth performance, carcass characteristics and organ weights (experiment 1)

Growth performance from weaning to the start of the experimental period did not ($P > 0.05$; data not shown) differ among the experimental groups, despite that C pigs were castrated only at 53 days of age. Over the entire experimental period, C pigs tended to grow faster ($P < 0.10$) than EMG pigs, ingested more ($P < 0.05$) feed and were less ($P < 0.05$) feed efficient than IC and EMG pigs (Table 2). There was no difference in overall ADG between IC and EMG ($P > 0.05$). Due to the higher feed intake of IC compared to EMG, FCR was better for EMG ($P < 0.05$). During the late finishing period, which varied from 23 to 44 days, IC pigs grew faster ($P < 0.05$) than EMG and C pigs and, together with C pigs, ingested more ($P < 0.05$) feed than EMG pigs. However, during this period, IC and EMG pigs had a better feed efficiency

Table 2 *Growth performance, carcass characteristics and organ weights of barrows (C), immunocastrated (IC) and entire male pigs (EMG) raised in group pens (experiment 1)*[†]

	Experimental group			
	C	IC	EMG	s.e.
Initial BW (kg)	27.3	28.0	27.7	0.52
BW at feed change (kg)	63.0^{ab}	62.1^{b}	63.5^{a}	0.44
Final BW (kg)	106.9	107.2	107.0	1.28
Average daily gain (g/day)				
Growing period	834^{a}	774^{b}	784^{ab}	22.3
Early finishing period	1037^{d}	866^{e}	890de	49.0
Late finishing period	1007^{b}	1136^{a}	1030^{b}	25.3
Growing–finishing period	931^{d}	920de	883^{e}	19.7
Average daily feed intake (kg/day)				
Growing period	1.80^{a}	1.63^{b}	1.65^{b}	0.040
Early finishing period	2.57^{a}	2.10^{b}	2.19^{b}	0.082
Late finishing period	3.09^{a}	3.10^{a}	2.62^{b}	0.049
Growing–finishing period	2.36^{a}	2.22^{b}	2.06^{c}	0.046
Feed conversion ratio (kg/kg)				
Growing period	2.16	2.11	2.11	0.028
Early finishing period	2.50	2.49	2.48	0.096
Late finishing period	3.08^{a}	2.74^{b}	2.55^{b}	0.064
Growing–finishing period	2.54^{a}	2.41^{b}	2.34^{c}	0.025
Age at slaughter (days)	161.0	161.1	164.1	2.5
Carcass characteristics				
Hot carcass weight (kg)	85.0	83.9	84.0	1.18
Cold carcass weight (kg)	82.9	81.9	81.9	1.15
Carcass yield (%)	79.5^{a}	78.3^{b}	78.6^{b}	0.3
Cold loss (%)	2.43	2.46	2.57	0.066
Lean meat (%)	54.5^{c}	56.3^{b}	57.5^{a}	0.35
Loin (%)	24.3^{b}	24.6^{b}	25.4^{a}	0.19
Ham (%)	18.0^{b}	18.9^{a}	19.0^{a}	0.17
Shouder (%)	12.2^{b}	12.9^{a}	13.1^{a}	0.14
Belly (%)	18.6^{a}	17.9^{b}	17.8^{b}	0.21
Subcutaneous fat (%)	15.3^{a}	13.8^{b}	12.8^{c}	0.32
10th rib fat thickness (mm)	24.9^{a}	19.3^{b}	17.8^{c}	0.94
Organ weights				
Heart (g)	395	393	410	9.0
Liver (g)	1595^{e}	1736^{d}	1636de	55.8
Kidney (g)	331	350	332	9.0
Testis (g)	–	299^{b}	584^{a}	30.4
Salivary gland (g)	40^{c}	46^{b}	68^{a}	24
Bulbourethral gland				
Weight (g)	7^{c}	47^{b}	139^{a}	8.6
Length (cm)	5.3^{c}	8.2^{b}	11.7^{a}	0.38

[a–c]Within a row, least square means for experimental treatments without a common superscript differ ($P < 0.05$).

[d,e]Within a row, least square means for experimental treatments without a common superscript differ ($P < 0.10$).

[†]Abbreviations are: BW at feed change = BW when the grower diet was switched to the finisher diet; early finishing period = 63 kg BW until the time point of second vaccination at 73 kg BW; late finishing period = from second vaccination to slaughter at 107 kg BW; carcass yield = hot carcass weight expressed as the percentage of the BW at slaughter; cold loss = cold carcass weight expressed as the percentage of the hot carcass weight; lean meat percentage = sum of denuded shoulder, back and ham weights as percentage of cold carcass weight; subcutaneous fat percentage = sum of external fat from the shoulder, back and ham expressed as percentage of cold carcass weight.

($P < 0.05$) than C pigs. In accordance to the lacking differences in the overall ADG, age at slaughter did not ($P > 0.05$) differ among the experimental groups.

Carcass yield in the IC and EMG groups was lower ($P < 0.05$; Table 2) than in the C experimental group. The carcasses of C pigs were fatter than those of IC, which themselves were fatter ($P < 0.05$) than those of EMG pigs. The percentages ham and shoulder were lower, and the percentage belly was greater ($P < 0.05$) in C than IC and EMG pigs. The loin percentage did not ($P > 0.05$) differ between C and IC pigs, but was lower ($P < 0.05$) than in EMG pigs.

The liver tended ($P < 0.10$) to be heavier in IC pigs compared with C pigs, EMG pigs being intermediate. As expected, method of castration affected ($P < 0.05$) the weight of the testes, salivary and bulbourethral glands, being heavier in EMG than IC pigs. In accordance to the heavier weights, the bulbourethral glands of EMG pigs were longer ($P < 0.05$) than those of IC pigs. It is worth mentioning that the testes of one IC pig were heavier than those of four EMG pigs (553 *v.* 431, 471, 512 and 541 g). The time span from second vaccination to slaughter did not correlate with testes weight of IC ($r = -0.18$; $P > 0.05$). The bulbourethral glands were, without exception, lighter ($P < 0.05$) in IC than in EMG pigs. The lightest ($P < 0.05$) and shortest ($P < 0.05$) bulbourethral glands, and the lightest salivary glands ($P < 0.05$) were found in C pigs.

Effect of Improvac® or saline solution injection on body temperature and injection site (experiment 1)

After the first and second vaccination, the body temperature at 4 h post-injection was on an average 1.1 and 0.9°C higher ($P < 0.05$) in IC than in C and EMG pigs (Figure 1a and b). The visual observation and palpation of the injection site revealed overall low scores. No animal showed a score above 2. Higher scores ($P < 0.05$) were observed for IC than C and EMG pigs after the first (24 and 48 h) and the second vaccination (4 and 24 h; data not shown).

Meat quality and fatty acid composition of the adipose tissue (experiment 1)

Initial and ultimate pH, *L**, *a**, *b** values, as well as the percentages drip, thaw and cooking loss did not ($P > 0.05$) differ among the experimental groups (Table 3). However, total purge loss (sum of thaw and cooking loss) tended to be greater ($P < 0.10$) in the LM of EMG than C pigs, with intermediate values in the LM of IC pigs. Shear force values were higher ($P < 0.05$), indicating tougher meat, in the LM of C and EMG than IC pigs. The degree of saturation of the adipose tissue decreased ($P < 0.05$) from C to IC and from IC to EMG pigs (Table 4). These differences were mainly due to a decrease in the concentrations of palmitic (16:0), stearic (18:0) and eicosanoic acids (20:0), and concomitantly to an increase in levels of linoleic (18:2n-6) and arachidonic acids (20:4n-6). The tissue level of monounsaturated fatty acids (MUFA), especially oleic acid (18:1n-9), did not ($P > 0.05$) differ among the experimental groups. In accordance, the 18:1n-9/18:0 desaturation index increased ($P < 0.05$) from C to IC, and from IC to EMG. By contrast, the 16:1n-7/16:0 desaturation index was similar for C and IC but was higher ($P < 0.05$) for EMG pigs.

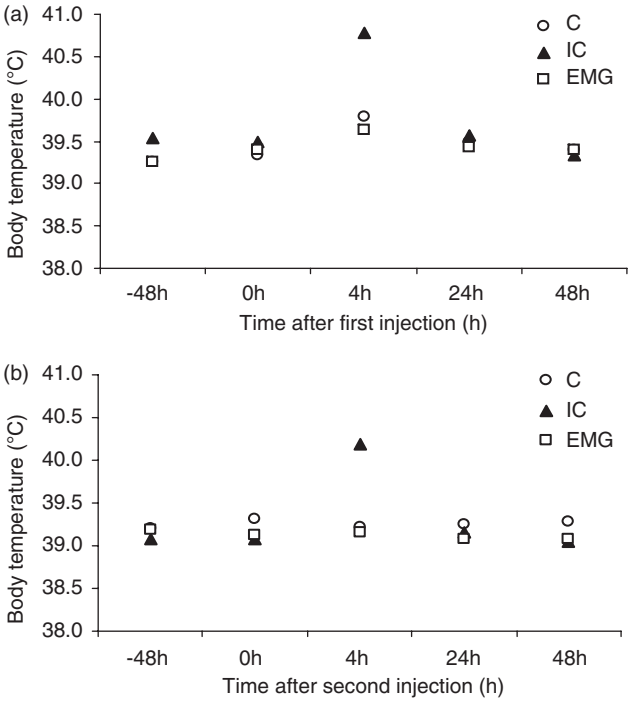

Figure 1 Body temperature determined −48 h before and 0, 4, 24 and 48 h after the first (a) and second (b) injection of barrows (C) and entire male pigs (EMG) with a saline solution and immunocastrated pigs (IC) with Improvac®.

Androstenone and skatole concentrations in the adipose tissue of group-penned animals (experiment 1)

The androstenone concentration in the adipose tissue of EMG pigs was higher ($P < 0.05$) than in IC and C pigs (Table 5). A large variability in the androstenone concentration was observed in the adipose tissue of EMG pigs, ranging from below detection limit ($\leqslant 0.20$ μg/g) to 1.9 μg/g. Except for one IC pig (0.3 μg/g), the androstenone concentrations in the adipose tissue of all C and IC pigs were below the detection limit of the HPLC method used. As observed for androstenone, the skatole concentrations in the adipose tissue of the EMG pigs were greater ($P < 0.01$) than in the adipose tissue of both the C and IC pigs. The skatole concentrations in the adipose tissue of four EMG pigs were high (0.21, 0.21 and 0.24 μg/g) or very high (1.23 μg/g). The indole level in the adipose tissue was not ($P > 0.05$) influenced by the method of castration and was very low. When data from C, IC and EMG pigs were combined, androstenone tissue concentration was correlated with skatole levels ($r = 0.46$; $P < 0.05$). Both, androstenone and skatole tissue concentrations were positively ($P < 0.05$) correlated with the weight of the salivary ($r = 0.83$ and 0.43) and bulbourethral glands ($r = 0.81$ and 0.66), as well as with the length of the bulbourethral glands ($r = 0.76$ and

Table 3 *Meat quality traits determined in the longissimus muscle from barrows (C), immunocastrated (IC) and entire male pigs (EMG) raised in group pens (experiment 1)*[†]

	Experimental group			
	C	IC	EMG	s.e.
Initial pH	6.20	6.22	6.28	0.495
Ultimate pH	5.50	5.49	5.49	0.167
*L**	50.1	51.0	50.3	0.34
*a**	6.5	6.1	6.5	0.21
*b**	2.8	2.7	2.7	0.18
Water holding capacity				
Drip loss (%)	4.06	4.22	4.56	0.394
Thawing loss (%)	11.19	12.09	12.52	0.619
Cooking loss (%)	15.80	15.61	16.84	0.540
Total purge loss (%)	25.18[d]	25.81[de]	27.25[e]	0.813
Shear force (kg)	3.70[a]	3.45[b]	3.77[a]	0.092

[a,b]Within a row, least square means for experimental treatments without a common superscript differ ($P < 0.05$).
[d,e]Within a row, least square means for experimental treatments without a common superscript differ ($P < 0.10$).
[†]Abbreviations are: total purge loss = total weight loss of a loin chop collected the day after slaughter, vacuum-packaged and stored at −20°C for several months, subsequently thawed overnight at 4°C and then cooked to an internal temperature of 69°C expressed as percentage of the initial weight of the fresh loin chop.

Table 4 *Fatty acid composition of the adipose tissue from barrows (C), immunocastrated (IC) and entire male pigs (EMG) raised in group pens (experiment 1)*[†]

	Experimental group			
	C	IC	EMG	s.e.
Total fatty acids	862.8[a]	838.1[b]	839.1[b]	5.10
14:0	1.44[a]	1.37[b]	1.34[b]	0.028
16:0	26.20[a]	25.45[b]	24.14[c]	0.298
18:0	15.21[a]	14.34[b]	13.15[c]	0.284
20:0	0.22[a]	0.19[b]	0.17[c]	0.007
Total SFA	43.79[a]	42.02[b]	39.49[c]	0.553
16:1n-7	2.55	2.62	2.70	0.069
18:1n-9	38.76	39.08	38.96	0.389
20:1n-9	0.79[a]	0.73[ab]	0.66[b]	0.044
Total MUFA	42.59	42.87	42.78	0.407
18:2n-6	11.48[c]	12.77[b]	15.01[a]	0.378
20:2n-6	0.56[b]	0.59[b]	0.66[a]	0.022
20:4n-6	0.27[c]	0.33[b]	0.41[a]	0.017
22:4n-6	0.10[b]	0.12[a]	0.13[a]	0.004
18:3n-3	1.02[b]	1.09[b]	1.29[a]	0.035
20:3n-3	0.12[b]	0.13[b]	0.14[a]	0.005
22:5n-3	0.04[b]	0.07[a]	0.08[a]	0.007
Total PUFA	13.61[c]	15.10[b]	17.71[a]	0.439
Desaturation index				
16:1n-7/16:0	0.10[b]	0.10[b]	0.11[a]	0.003
18:1n-9/18:0	2.56[c]	2.74[b]	2.98[a]	0.072

[a–c]Within a row, least square means for experimental treatments without a common superscript differ ($P < 0.05$).
[†]Abbreviations are: SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids; fatty acids are expressed as g/100 g total fatty acids. Fatty acids were designated by the number of carbon atoms followed by the number of double bonds. The position of the first double bond relative to the methyl(n) end of the molecule was also included.

Table 5 *Androstenone, skatole and indole concentrations (expressed in μg/g tissue) in the adipose tissue of barrows (C), immunocastrates (IC) and entire male pigs (EMG) raised in group pens (experiment 1)*[†]

	Experimental groups		
	C	IC	EMG
Androstenone			
Mean	⩽0.2[a]	0.2[a]	0.7[b]
Min–max		⩽0.2–0.3	⩽0.2–1.9
Skatole			
Mean	0.03[a]	0.05[a]	0.19[b]
Min–max	⩽0.03–0.06	⩽0.03–0.09	⩽0.03–1.23
Indole			
Mean	⩽0.03	⩽0.03	0.04
Min–max			⩽0.03–0.09

[a,b]Within a row, least square means for experimental treatments without a common superscript differ ($P < 0.05$).
[†]The detection limits of the used HPLC procedure are (expressed as μg/g adipose tissue): androstenone = 0.2 μg, skatole and indole = 0.03 μg.

0.61). Analyses of the combined data from IC and EMG revealed increasing androstenone ($r = 0.81$; $P < 0.05$) and skatole ($r = 0.37$; $P = 0.07$) tissue levels with increased testes weights.

Growth performance, carcass characteristics and organ weights (experiment 2)

In the growing and finishing periods, EMP pigs consumed more ($P < 0.05$) feed than EMG ones and had a poorer feed efficiency ($P < 0.05$) (Table 6). However, ADG did not differ ($P > 0.05$) among the experimental groups. Compared with EMG pigs, the carcasses of EMP pigs tended ($P = 0.09$) to have less lean meat mainly due to lighter ($P = 0.10$) loins. The testes, but not the salivary and bulbourethral glands, tended ($P = 0.07$) to be heavier in EMP than in EMG pigs.

Meat quality, fatty acid composition, androstenone, skatole and indole concentrations of the adipose tissue (experiment 2)

Initial and ultimate pH, as well as percentages drip, thaw and cooking loss of the LM did not differ ($P \geqslant 0.16$; data not shown) among the experimental groups. Compared with EMP, the LM of EMG pigs was redder (*a**: 6.4 *v.* 6.0; s.e.: 0.17; $P < 0.05$) and shear force values were lower (3.8 *v.* 4.1 kg; s.e.: 0.11; $P < 0.01$). The numerically higher saturated fatty acids (SFA) (EMP = 40.4% *v.* EMG = 39.7%; s.e.: 0.61; $P > 0.05$) and MUFA (EMP = 43.4% *v.* EMG = 42.7%; s.e.: 0.50; $P > 0.05$) concentrations in the adipose tissue of EMP pigs were compensated by lower polyunsaturated fatty acid (PUFA) concentrations (EMP = 16.3% *v.* EMG = 17.7%; s.e.: 0.48; $P < 0.01$). Responsible for these differences were the lower ($P < 0.01$) linoleic (13.9% *v.* 15.0%; s.e.: 0.41), arachidonic (0.3% *v.* 0.4%; s.e.: 0.02), docosatetraenoic (0.10% *v.* 0.13%; s.e.: 0.004), linolenic (1.2% *v.* 1.3%; s.e.: 0.04) and docosahexaenoic acid (0.05% *v.* 0.08%; s.e.: 0.007) tissue concentrations in EMP compared with EMG pigs.

Table 6 *Growth performance, carcass characteristics and organ weights of entire male pigs reared in group pens (EMG) or in individual pens (EMP) (experiment 2)*[†]

	Experimental groups			
	EMG	EMP	s.e.	*P*-values
Initial BW (kg)	27.6	27.0	0.42	0.23
BW at feed change (kg)	63.5	63.5	0.49	0.91
Final BW (kg)	107.1	108.1	1.21	0.32
Average daily gain (g/day)				
Growing period	777	788	16.6	0.64
Finishing period	984	999	30.3	0.63
Growing–finishing period	879	890	18.4	0.55
Average daily feed intake (g/day)				
Growing period	1.64	1.84	0.034	<0.001
Finishing period	2.49	2.66	0.053	0.02
Growing–finishing period	2.05	2.24	0.040	<0.01
Feed conversion ratio (kg/kg)				
Growing period	2.10	2.34	0.039	<0.001
Finishing period	2.53	2.68	0.053	0.04
Growing–finishing period	2.33	2.52	0.036	<0.001
Age at slaughter (days)	164.8	165.9	2.66	0.70
Carcass characteristics				
Cold carcass weight (kg)	82.1	82.7	1.19	0.57
Lean meat (%)	57.4	56.4	0.40	0.09
Loin (%)	25.4	24.8	0.24	0.10
Ham (%)	19.0	18.8	0.23	0.11
Shouder (%)	13.0	12.8	0.13	0.11
Belly (%)	17.8	17.7	0.26	0.74
Subcutaneous fat (%)	12.8	13.4	0.31	0.17
10th-rib fat thickness (mm)	17.8	16.2	1.15	0.23
Organ weights				
Testis (g)	584	658	32.3	0.07
Salivary gland (g)	69	74	4.47	0.16
Bulbourethral gland				
Weight (g)	141	139	12.2	0.89
Length (cm)	11.8	11.7	0.41	0.80

[†]Abbreviations are: *P*-values = probability values for the experimental treatment; lean meat percentage = sum of denuded shoulder, back and ham weights as percentage of cold carcass weight; subcutaneous fat percentage = sum of external fat from the shoulder, back and ham expressed as percentage of cold carcass weight.

No differences ($P > 0.05$) in the androstenone, skatole and indole concentrations were detected in the adipose tissue between EMP and EMG pigs. Androstenone tissue concentrations were positively ($P < 0.05$) correlated with skatole levels ($r = 0.81$), salivary glands weight ($r = 0.48$), bulbourethral glands weight ($r = 0.45$) and length ($r = 0.44$), but not ($P > 0.05$) with the weights of testes. The level of skatole was not ($P > 0.05$) correlated with the anatomical parameters ($P < 0.05$).

Discussion

Castration leads to a drastic reduction of the gonadal steroids synthesis, such as androgens and estrogens (Claus *et al*., 1994). By doing so, the anabolic potential of the pig is modified, thereby affecting growth performance, carcass composition and pork quality. Compared to barrows, IC pigs keep this anabolic potential for a much longer period of time (Metz and Claus, 2003), which is of high practical relevance. In experiment 1, the ADG of IC pigs confirms those obtained in a recent Swiss field study (Jaros *et al*., 2005). Despite the lower ADG of IC pigs during the growing period, the overall growth rate did not differ from C pigs, due to the higher ADG after the second vaccination (late finishing period). During the same period, IC pigs had higher ADFI and ADG than EMG pigs. These findings are in agreement with recent results of other studies (Zeng *et al*., 2002; Oliver *et al*., 2003). In contrast, Metz *et al*. (2002) obtained comparable ADG, FCR and backfat thickness in immunocastrates and barrows. In comparison to the present study (second vaccination: 23 to 44 days before slaughter), Metz *et al*. (2002) applied the second immunization earlier (10th and 16th-week of age), thus shortening the phase during which the animal can profit from the anabolic potential of the entire male. The timing of the second vaccination is likely to be a key reason for the observed differences. The observed differences in appetite, before and after the second vaccination, could be related to drastic changes in testosterone concentration. According to Claus and Weiler (1987), the application of a testosterone implant reduced feed intake of barrows by about 25%. While the testosterone levels have been shown to drop quickly after the second vaccination (Claus *et al*., 2007), Metz and Claus (2003) determined that the growth hormone concentration in the plasma of immunocastrates remained close to those of entire males for several weeks. This might explain the observed compensatory growth after immunocastration (Bonneau *et al*., 1994).

As the vaccination lowers testosterone production, it is likely to decrease the aggressive behaviour, which is related to the testosterone concentration (Giersing *et al*., 2000). At 2 weeks after the second Improvac® injection, Velarde *et al*. (2008) observed less activity and a lower number of mounts in immunocastrates than entire males. Consequently, immunocastrates had less time for general activity and social behaviour than entire males. This lower behavioural activity may account for better feed conversion, because the energetic cost of being standing is very high in pigs (Noblet *et al*., 1993).

An additional consequence of the higher ADFI of IC compared to EMG pigs after the second vaccination, was the fatter carcasses. However, the benefits of the sexual hormones before the second vaccination were not completely lost, as IC pigs had an overall higher feed efficiency and their carcasses were leaner compared to barrows. Differences in percentage lean meat between the IC and C groups are due to higher percentage of ham and shoulder, but not of loin. Muscle associated with mobility (muscles of the fore and hind limb) have been shown to develop earlier in life (Richmond and Berg, 1982). By contrast, allometric growth coefficients of muscles involved with posture, such as the LM, are higher. Thus, they may be regarded as

developmentally retarded muscles (Bee *et al*., 2007). As the second vaccination reduces the anabolic potential in the late finishing period, LM development might be more affected than ham and shoulder.

Not only carcass fatness, but also the lipid content of the subcutaneous fat differed among the experimental groups, being lower in EMG and IC, than in C pigs, which is in line with results reported by Barton-Gade (1987). Besides the impact on lipid content, the fatty acid composition also differed between experimental groups. The palmitic, stearic and total SFA concentrations increased and the linoleic, arachidonic and total PUFA decreased in the adipose tissue from EMG to IC, and from IC to C pigs. No changes among the experimental groups were observed for the oleic and total MUFA concentrations. In accordance to these findings, differences in the fatty acid composition between entire males and barrows have been reported in earlier studies as well (Wood *et al*., 1986; Barton-Gade, 1987). These differences in the fatty acid composition, especially the level of PUFA, were mainly related to changes in the rate of subcutaneous fat deposition (Wood and Enser, 1982). The proportion of oleic acid, the main MUFA in swine adipose tissue, is determined by the dietary supply, as well as by the elongation and desaturation of the saturated homologues. The desaturation step is influenced by dietary PUFA of the n-6 family, which are known to impair the activity of the stearoyl-CoA desaturase (Kouba and Mourot, 1998). In the present study, the desaturation indexes (ratios: palmitoleic to palmitic acid and oleic to stearic acid) were calculated, which are known to relate well with the activity of the stearoyl-CoA desaturase (Klingenberg *et al*., 1995; Kouba *et al*., 1997). Compared to the IC and EMG groups, conversion of palmitic and stearic acids into their desaturated homologues was decreased in the adipose tissues of C pigs. This suggests a regulatory effect of dietary PUFA intake on stearoyl-CoA desaturase activity. Due to the higher ADFI, dietary PUFA intake was greater in C pigs compared to pigs in the other experimental groups. To our knowledge, no information on the fatty acid composition of the adipose tissue from immunocastrates is available. In accordance to the aforementioned relationship between fat deposition rate and PUFA concentration, the degree of unsaturation in IC pigs was intermediate between C and EMG pigs, as was the case with the backfat thickness.

In contrast to the profound differences in fat quality, only pork tenderness, as assessed by the shear force measurements in the LM, differed among the experimental groups, being higher in C than in IC and EMG pigs. A plausible cause for this difference could be the compensatory growth of IC, compared to C and EMG pigs, at the end of the finishing period. Recently, Kristensen *et al*. (2002) and Bee *et al*. (2006) reported that compensatory growth before slaughter is followed by an increased proteolytic potential (μ-calpain : calpastatin ratio) and higher tenderization rate.

After the second vaccination, anti-GnRH response markedly inhibits testes growth. In accordance to results reported by Dunshea *et al*. (2001), testes of IC pigs were 51% lighter than testes of EMG pigs. Based on this finding, testes weights could be used to judge good vaccination practice at the slaughter line. However, a complete discrimination is not possible because as shown in the present study, the testes of one IC pig were heavier than those of four EMG pigs. Based on results of earlier studies, testes weight is highly correlated with BW in entire males (Prunier *et al*., 1987). Similarly, we report that testes of IC pigs are also heavier when slaughter weight increases. Thus, both traits, testes and slaughter weight together, could be used to judge the effectiveness of vaccination.

Through changes in liver metabolism, a reduction of the androstenone concentration implicates also a reduction of the skatole concentration in the adipose tissue. Several studies (Dunshea *et al*., 2001; Jaros *et al*., 2005; Zamaratskaia *et al*., 2008) have demonstrated a very consistent effect of Improvac® on both, androstenone and skatole levels, with proper vaccine application. Our findings confirm this effect, as the androstenone, skatole and indole concentrations in the adipose tissue of all IC pigs were clearly below the sensory thresholds set by Walstra *et al*. (1999), while some of the EMG littermates had concentrations above these limits.

Similar to results of an earlier experiment (Pauly *et al*., 2008), EMG pigs tended to grow slower than C. This low growth rate was associated with a low feed intake. Although ADFI in the present study tended to be higher than in the aforementioned study (2.06 *v.* 1.90 kg/day), overall the ADFI of entire males was still low. Cronin *et al*. (2003) and Zeng *et al*. (2002) also observed lower dietary energy intake of entire males than barrows. The low feed intake could be related to the negative influence of sexual hormones. Claus and Weiler (1987) reported that increased oestrogen and androgen concentrations inhibit feed intake. Thus, the low feed intake could limit the intake of essential nutrients. The lysine concentration of the diets was slightly lower compared to recent published recommendations (9.2 *v.* 9.6 g/kg dry matter; O'Connell *et al*., 2006). Therefore, one could hypothesize that the lysine intake was below the required level for maximal protein accretion of entire males, thereby further limiting their growth rate.

In experiment 2, EMP consumed more feed than EMG, however, ADG was similar for both groups. The higher feed intake is in agreement with results from other studies (de Haer, 1992; Nielsen *et al*., 1996), showing that the feeding behaviour of individually penned pigs (castrates and females) differ significantly from that of group-penned animals, with individual penning resulting in shorter, more frequent visits of the feeder and overall higher ADFI. However, the higher ADFI of EMP compared with EMG was not sufficient to affect growth rate. It is unlikely that differences in social thermoregulation caused differences in ADFI because the air temperature and relative humidity in the building was 22°C and 60% to 70%, respectively. As mentioned earlier, dietary lysine concentration could have been a limiting factor in entire males in this study. Total lysine intake was higher in EMP than EMG pigs. Nevertheless, there was

no extra response on weight gain. It is worth mentioning the larger variability (standard deviation within experimental group) in ADG of EMP than EMG (125 *v.* 72 g/day) during the finishing period, while the variability in ADFI (202 *v.* 161 g/day) did not differ. This could suggest that the response to individual housing differed among EMP pigs.

In the present study, very low to quite high androstenone and skatole concentrations were measured in the adipose tissue of entire male pigs. By combining data of EMG and EMP, four (15%) entire male pigs were above the sensory threshold for androstenone (⩾1.0 μg/g adipose tissue) and eight (31%) above the threshold for skatole (⩾0.16 μg/g adipose tissue). This high incidence of boar taint confirms results of an earlier study carried out under similar conditions with pigs of the same genetic background (Pauly *et al.*, 2008). The rearing conditions did not affect the androstenone and skatole concentrations in the adipose tissue. The number of entire male pigs having concentrations of androstenone and skatole above the aforementioned threshold limits was equal in both experimental groups.

In conclusion, EMP ingested markedly more feed under *ad libitum* conditions than EMG, but ADG did not differ. Immunocastrated entire male pigs had an improved feed efficiency and leaner carcasses compared with barrows. By contrast, when compared to entire males, immuncastration reduced carcass leanness and increased feed efficiency. The present results confirm that androstenone and skatole concentrations can be efficiently controlled by vaccination with Improvac®. Contrarily, the risk for boar tainted pork remained elevated when raising entire Swiss Large White males. Thus, immunocastration offers a good and reliable alternative to avoid castration and produce pork free of boar taint.

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